

Perioperative use of somatosensory evoked responses in aneurysm surgery

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✓ Somatosensory evoked potentials have been recorded during 34 operations for intracranial aneurysm. The central conduction time (CCT), the time between the N₁₄ peak (recorded at C-2) and the N₂₀ peak (recorded at the cortex) in response to median nerve stimulation, has been found to be increased by administration of halothane, by brain retraction, and by temporary vascular occlusion in some instances. Increase of CCT to more than 10 msec, or disappearance of the response was associated in two cases with postoperative neurological deficit, neither permanent. In a further case, prolongation of CCT was used as a guide to the repositioning of an imperfectly placed clip on a middle cerebral artery aneurysm. The value of the technique as a perioperative monitoring system is discussed.

KEY WORDS • cerebral ischemia • somatosensory evoked potentials • central conduction time • intracranial aneurysm • halothane • brain retraction

THE demonstration of a critical cerebral blood flow threshold for the maintenance of electrical activity in the primate cortex²⁻⁴ indicates the potential of continuous electrical recording as a means of monitoring the adequacy of the cerebral circulation during surgery. The use of the somatosensory evoked potentials (SEP's) in the study of aneurysm patients has been reported,⁸ and this technique is now used in the operating room for repeated monitoring of cortical electrical activity during aneurysm surgery.

Clinical Material and Methods

Somatosensory evoked responses were recorded during intracranial surgery in 33 patients with 38 aneurysms that were clipped in a total of 34 operations. The patients included 13 males and 20 females, aged from 9 to 63 years. Twenty-six of the operations were carried out 2 days to 3 weeks following a subarachnoid hemorrhage (SAH), and in two other cases the SAH took place several months preoperatively. In six cases the operations were carried out for the obliteration of giant aneurysms. Three were compressing the visual pathways, and one was associated with an arteriovenous malformation. Two giant aneurysms were present in a patient who was operated on initially for facial pain from a giant basilar aneurysm and subsequently for a silent large middle cerebral artery aneurysm.

Somatosensory evoked responses were generated by stimulation of the median nerve at the wrist by square waves of 0.15-msec duration, and of an intensity determined at preoperative recording to be three times the subjective threshold and adequate to sustain a small thumb twitch. Bipolar stimulating electrodes were placed with the cathode 3 cm proximal to the anode, and the rate of stimulation was 3/sec. The technique was modified from that of Hume and Cant,⁵ and has been described previously.^{8,10}

Recording electrodes were placed over the surface of the spine at C-2 and over the areas of the somatosensory cortex bilaterally, using the C3/4 position in the international 10/20 system. The frontal reference, Fpz, was used. Either 128 or 256 sweeps were averaged on a Digitimer D200 averager.* Central conduction time (CCT), defined as the time interval between the arrival of the impulse at the C-2 level and at the somatosensory cortex, representing conduction within the central nervous system itself, was used as the principal measurement, and the amplitude of the SEP's was also measured throughout the procedure.

The averager, amplifier, stimulus generator, and the

* Digitimer D200 averager manufactured by Digitimer, Welwyn, Hertfordshire, England.

oscilloscope were mounted on a mobile trolley and placed at the foot of the operating table. A group of preamplifiers were placed beneath the operating table, as close as possible to the patient's head, and the electrode wires were braided to avoid movement and to reduce the saturation of recording amplifiers from electrical and/or magnetic fields such as are generated by surgical instruments, the suction system, diathermy, headlight, television video recorders, or fluorescent lights.

The patients had initial recordings performed on the day before operation and, on the day of operation, electrodes were fixed in place after the induction of anesthesia and shaving of the scalp. The position of these recording electrodes is shown in Fig. 1. The recording was carried out continuously while the patient was placed on the operating table, throughout the surgical procedure, and again in the immediate postoperative period. A further recording was made on return to the ward after the patient had regained consciousness. Preoperative clinical grading according to the Hunt and Hess scale⁶ was carried out for each patient by one of us (L.S.). Ten patients were in grade 0 or I, eight in Grade II, five in Grade III, and 10 in Grade IV. There were 11 middle cerebral artery aneurysms, eight aneu-



FIG. 1. Schematic diagram showing the reference electrode at the nasion (Fpz) and the recording electrode at the scalp (C3/4 in the international 10/20 system), placed well away from the small frontotemporal skin flap used for the aneurysm surgery. The recording from the neck electrode is not shown in the figure.

rysms of the anterior communicating artery, 16 aneurysms of the internal carotid or the carotid/posterior communicating artery, and five aneurysms of the basilar artery.

Results

Effect of Surgery on Conduction

The effect of surgery on conduction through the central nervous system is shown in Table 1. Preoperative recordings in the 33 patients revealed a mean CCT of 5.8 ± 0.5 msec, with a range of 5.2 to 7.0 msec. There was no difference in the total group between these recordings and those of the normal control group (20 normal subjects with a mean CCT of 5.4 ± 0.4 msec) or of a group of SAH patients without aneurysms. When comparing the preoperative recordings in various grades, however, mean results ranged from 5.7 ± 0.4 msec in Grade I to 6.0 ± 0.5 msec in Grade IV patients. There was a significant difference only between Grade IV patients and control data ($p < 0.01$).

After the induction of anesthesia with thiopental and intubation, conduction slowed to a mean of 6.0 ± 0.6 msec, which was not significantly different from the immediate preoperative data. The standard form of maintenance of anesthesia in this clinic was by inhalational halothane in concentrations varying from 0.5% to 2%. This resulted in moderate hypotension and prolongation of CCT in all 33 cases. The average CCT after the maintenance of a stable level of anesthesia was 6.7 ± 0.7 msec, significantly longer than the preoperative recording ($p < 0.01$) and the recording during induction of anesthesia ($p < 0.05$). Figure 2 shows prolongation of CCT in response to a changing concentration of halothane. There was also a significant reduction in blood pressure during halothane anesthesia, with mean levels of blood pressure falling from 87.8 ± 15.8 to 70.1 ± 12.1 mm Hg after the attainment of a stable concentration of halothane ($p < 0.01$).

Opening the dura had no significant effect on conduction, but brain retraction caused significant CCT prolongation in a number of instances. Although the groups as a whole showed no significant change, CCT tended to be rather longer (mean 7.0 ± 0.9 msec, ranging from 5.4 to 9 msec) after application of self-retaining retraction. In four patients, conduction time in the retracted hemisphere exceeded that in the control

TABLE 1
CCT in both cerebral hemispheres at different operative stages*

Hemisphere	Pre-op	Induction of Anesth.	Increase Halothane	Open Dura	Brain Retraction	Dissection	Clipping		Reverse Anesth.	End of Operation	Regain Consc.
							Before	After			
affected side	5.8 ± 0.5	6.0 ± 0.6	6.7 ± 0.7	6.8 ± 0.7	7.0 ± 0.9	6.9 ± 0.8	6.9 ± 0.7	7.4 ± 1.2	7.2 ± 0.9	6.8 ± 0.7	6.1 ± 0.4
no. of cases	30	34	33	34	34	38	38	38	34	34	31
unaffected side	5.9 ± 0.5	6.1 ± 0.6	6.5 ± 0.7	6.7 ± 0.8	6.9 ± 0.8	6.8 ± 0.9	6.8 ± 1.0	6.8 ± 0.9	6.9 ± 1.0	6.8 ± 0.8	6.1 ± 0.5
no. of cases	30	30	29	30	31	30	27	30	29	29	31

* Values are means \pm standard deviations of central conduction times (CCT) in msec. Affected hemisphere is the side of operation.

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hemisphere by more than 0.6 msec (Fig. 3). During the dissection of the aneurysm and its parent vessels, CCT again became gradually prolonged; the mean CCT during this stage was 7.1 ± 0.8 msec, and ranged from 5.8 to 9.0 msec, although these values are not statistically different from earlier stages of the operation.

The application of an aneurysm clip to 13 aneurysms in 12 of the 33 patients resulted in a significant prolongation of CCT, varying from 0.4 to 3 msec, with an average value of 7.4 ± 1.2 msec. This was significantly different from the CCT recorded before clipping ($p < 0.05$). The remaining cases showed no change of CCT during this phase.

Effects of Temporary Clips

Temporary clips were applied to major vessels in 15 patients: four to the terminal carotid artery, six to the middle cerebral artery, four to one or both of the proximal anterior cerebral arteries, and one to the internal carotid artery above and below the aneurysm neck and to the posterior communicating artery behind the aneurysm. In nine cases there was no detectable change in CCT, even when the terminal carotid, middle cerebral, or anterior cerebral arteries were clipped. In the other six cases, there was an immediate and significant prolongation of CCT by up to 3 msec within 3 minutes of clipping, and in one case the N₂₀ peak could not be identified in the affected hemisphere after the application of three temporary clips, as described above (Fig. 4).

Removal of temporary clips resulted in the recovery of conduction velocity to the immediately preceding level within 15 minutes, except in the single case of triple vascular occlusion when a recognizable potential appeared within 8 minutes, but the potential did not approach the preceding level until 40 minutes had elapsed (Fig. 4). A summary of several interesting cases is given below.

Following the application of clips to the aneurysm, the standard surgical procedure was to elevate the blood pressure from a mean level of between 60 and 70 mm Hg to the patient's normal blood pressure, and to reverse the neuromuscular blockade used for respiratory paralysis. In general, this had no effect on CCT; however, in eight cases CCT became further prolonged during this phase of the procedure, in all cases but one after the development of spontaneous respiration. In the four cases where pCO₂ values were recorded at this stage, each was above 40 mm Hg. Prolongation of between 0.4 and 1.2 msec lasted a short time only or until the patient regained consciousness.

By the close of the procedure and the application of a head bandage, CCT had recovered to an average value

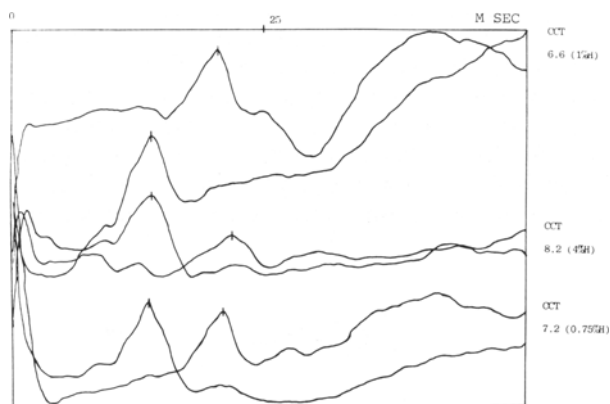


FIG. 2. The effect of changing halothane (H) concentrations on central conduction time (CCT). The CCT increased from 6.6 to 8.2 msec when halothane increased from 1% to 4%, and returned to 7.2 msec when halothane was reduced to 0.75%. In the upper pair of traces, the scalp electrode is the upper trace. In the middle and lower pairs, the upper trace is from the neck electrode.

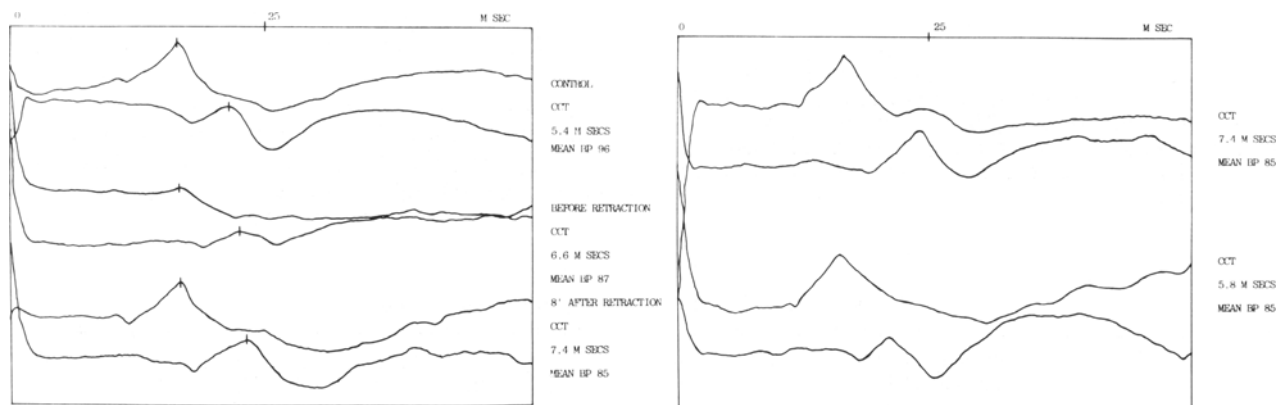
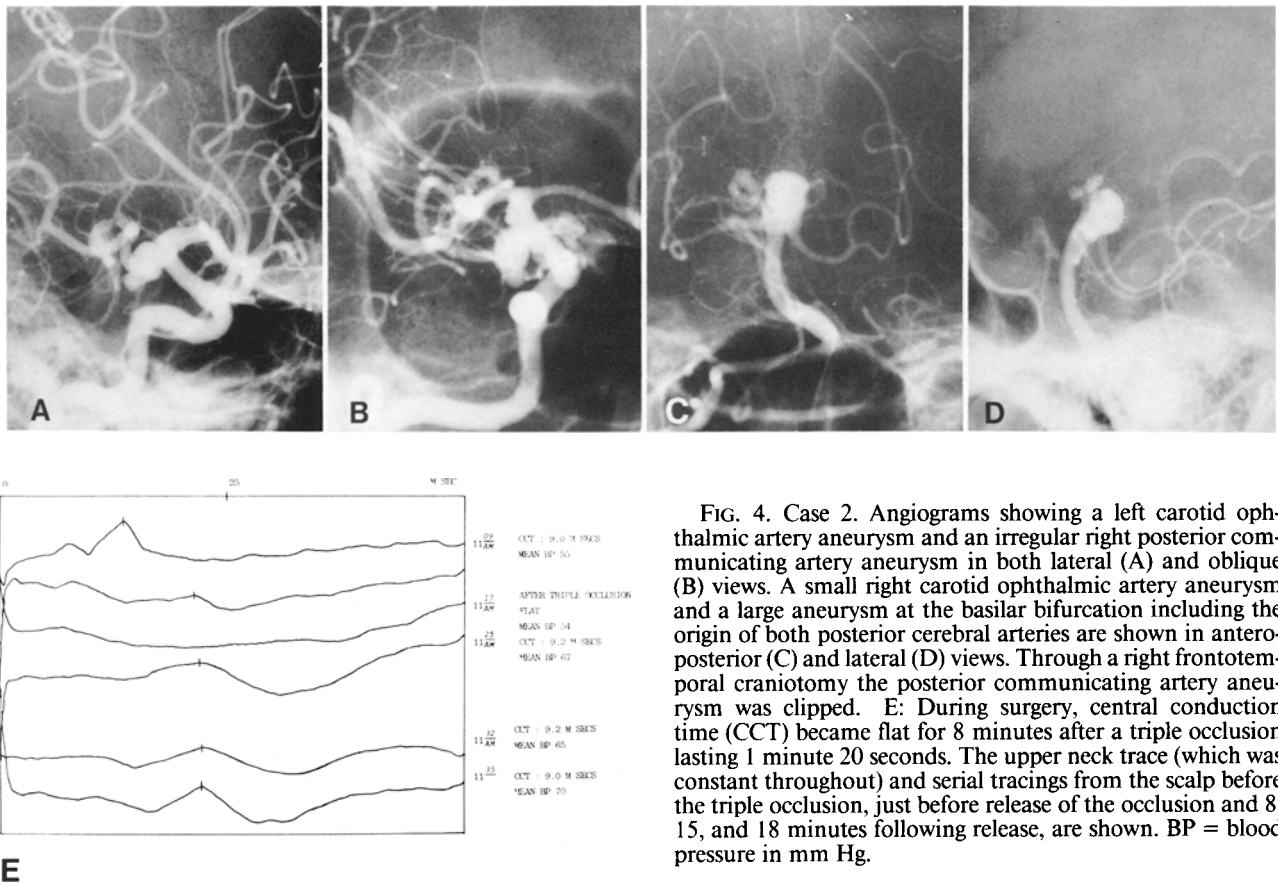


FIG. 3. Effect of brain retraction: brain retraction prolonged central conduction time (CCT) in the operated hemisphere from 6.6 to 7.4 msec (left), with a 1.6-msec interhemispheric difference (right). Left: In each pair of traces the upper trace is the neck electrode. Right: Upper pair of traces is recorded from the affected hemisphere, the lower pair is from the unaffected hemisphere. In each pair, the upper trace is from the neck electrode. BP = blood pressure in mm Hg.



of 6.8 ± 0.7 msec, still significantly longer than at induction of anesthesia ($p < 0.01$), but, by the time the patients had regained consciousness in the recovery room, the CCT had recovered to 6.1 ± 0.4 msec, significantly shorter than at the close of the operation ($p < 0.01$) and not significantly different from the preoperative levels.

Amplitude Measurements

Measurements of SEP's during induction of anesthesia showed generally slight decreases in amplitude which were less striking than delays in conduction (Table 2). Alterations in conduction velocity could be detected at various stages throughout the procedure before a measurable decline in SEP amplitude was noted; however,

during occlusion of major vessels, as the conduction time became prolonged, SEP amplitude declined rapidly, and in some instances the potential could scarcely be detected. The ratio between the N_{20} and N_{14} amplitudes disclosed no extra information except during occlusion, and the same was true of comparison between the two hemispheres. Only in the circumstances of individual hemisphere retraction or occlusion of the vessel on one side did the amplitude of the two tracings differ. Measurements of SEP amplitude were, in addition, complicated by incidental noise to a much greater extent than the measurement of conduction velocity, although with improved techniques of recording in the operating room it may well be that amplitude measurements will have increasing value.

TABLE 2
Effect of surgery on somatosensory evoked potential amplitude ratio (N_{20}/N_{14})*

Hemisphere	Induction of Anesth.	Increase Halothane	Open Dura	Brain Retraction	Dissection	After Clipping	Reverse Anesth.	End of Operation
affected side no. of cases	0.82 ± 0.40 27	0.73 ± 0.28 24	0.81 ± 0.39 19	0.74 ± 0.13 22	0.82 ± 0.54 22	0.81 ± 0.37 23	0.84 ± 0.40 23	0.93 ± 0.38 20
unaffected side no. of cases	0.74 ± 0.41 26	0.74 ± 0.28 24	0.81 ± 0.39 19	0.82 ± 0.54 22	0.94 ± 0.67 21	0.80 ± 0.37 23	0.84 ± 0.40 23	0.92 ± 0.38 20

* Values are means \pm standard deviations in msec. Affected hemisphere is the side of operation.

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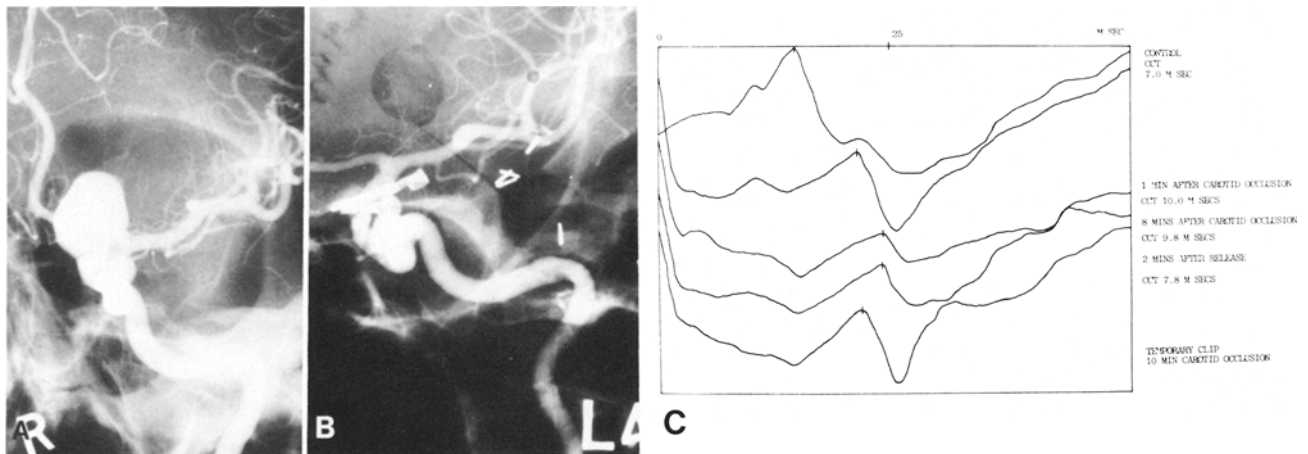


FIG. 5. Case 1. Angiograms revealing a giant left internal carotid ophthalmic artery aneurysm (A) which was occluded with a Sugita clip (B). During surgery, temporary clips were applied for 10 minutes to the internal carotid artery both in the neck and intracranially distal to the aneurysm. The central conduction time increased to 10 msec after application of the clips. C: A neck trace above and serial scalp traces, before carotid occlusion, 1 and 8 minutes after carotid occlusion had begun, and 2 minutes after release of the clips.

Illustrative Cases

Case 1

This 59-year-old woman had an 18-month history of progressive deterioration of vision in the left eye, with left optic atrophy. Her visual acuity was reduced to 3/60, with a large central scotoma. Angiography revealed a giant aneurysm of the internal carotid-ophthalmic artery. The CCT rose to 10 msec on application of carotid intracranial and extracranial clips (Fig. 5), and took 30 minutes to return to the pre-clip level after removal of the temporary clips. The patient had a diminished level of consciousness without clear hemispheric signs for 4 weeks. The clinical picture was complicated by a leak through the aneurysm clip into the interhemispheric fissure, which may have contributed to the depressed level of consciousness. The patient went on to make a full recovery within 2 months without hemispheric deficit. Vision in the left eye improved.

Case 2

This 50-year-old woman had a history of SAH without coma 2 months prior to admission. Angiography showed multiple aneurysms. The N_{20} wave disappeared following temporary triple vascular occlusion during obliteration of a difficult posterior communicating artery aneurysm and basilar tip aneurysm at the same operation. She had an unidentifiable N_{20} peak for about 8 minutes after 1 minute and 20 seconds of vascular occlusion. There was an appropriate postoperative hemispheric deficit of dysphasia and left-sided hemiparesis which cleared slowly but completely over 3 months. This patient's tracings are shown in Fig. 4.

Case 3

This 58-year-old woman had a 10-year-history of

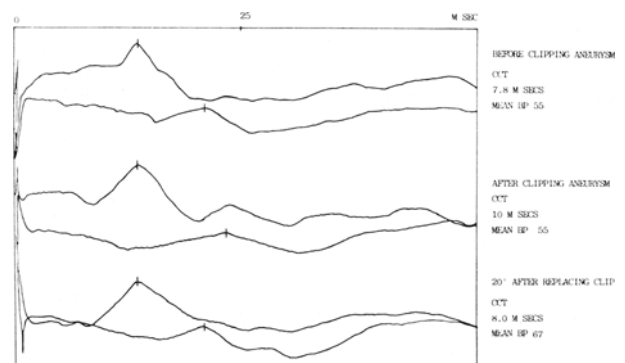


FIG. 6. Case 3. Central conduction time (CCT) was prolonged up to 10 msec during surgery when inadvertent occlusion of an opercular branch of the middle cerebral artery occurred, and was reduced promptly on repositioning the clip. There was no detectable neurological deficit and a smooth postoperative recovery. In each pair of traces, the upper is from the neck electrode. BP = blood pressure in mm Hg.

hypertension under regular medical control. She suffered a sudden severe headache 2 days before admission, and SAH was confirmed by lumbar puncture. Angiography showed an aneurysm on each middle cerebral artery. Computerized tomography showed blood in the left Sylvian fissure. There was no focal neurological signs, but she had mild neck stiffness and headache (Grade II). The left middle cerebral artery aneurysm was clipped 7 days after SAH. In the course of surgery, a clip was applied to inadvertently include an opercular branch of the middle cerebral artery. There was prolongation of the CCT up to 10 msec, but it then returned to normal on more appropriate positioning of the clip (Fig. 6). There was no detectable neurological deficit after the operation and the patient had a smooth recovery.

Discussion

Operations for intracranial aneurysms carry risk to the perfusion of the neural tissue supplied by the aneurysm-bearing artery. Soon after SAH, these dangers are compounded by altered reactivity in the basal vessels¹ and by the diminished or abolished autoregulatory capacity that has been shown to follow soon after SAH.⁷ In giant aneurysms the difficulty of handling these masses, often partially filled with clot, has led some surgeons to perform preliminary intra-extracranial bypass procedures, and has frequently necessitated temporary occlusion of major arteries while the lesion is manipulated, evacuated, and satisfactorily clipped. The demonstration in recent years of threshold relationships between blood flow and neuronal function^{2-4,10} prompted us to extend our techniques of electrical monitoring into the operating theater in an attempt to increase the safety of aneurysm surgery. The position of the indifferent and recording electrodes used for SEP recording in our hands is sufficiently far away from the small frontotemporal flap routinely used in surgery of the anterior circle of Willis, and SEP's may therefore be recorded throughout surgery without disturbing the operating surgeon. The operating room is, however, a hostile environment for recording of electrical conduction. The surgical manipulation, anesthetic agents, changes in blood pressure, and pCO₂ combine to diminish the ease of recording, and the electrical recordings themselves are much influenced by electromagnetic fields generated by diathermy apparatus, operating lights, microscopes, and television cameras.

Satisfactory SEP recording is possible with care, however; where bilateral responses can be recorded, unilateral conduction change is likely to result from surgical manipulation and may therefore be informative. Bilateral conduction changes relate more to anesthetic and metabolic factors. We have selected the N₁₄ to N₂₀ peak interval for monitoring CCT in view of our experience in the use of their parameters in pre- and postoperative monitoring following SAH.⁹ The N₁₄ latencies throughout the operation were remarkably constant. In this study, we found the preoperative recording differentiated only Grade IV patients in terms of CCT, their conduction time being significantly longer than normal control times. In perioperative recording, the response of all patients to anesthesia and brain retraction was not influenced by clinical grade. In the course of our study, CCT emerged as a sensitive index of the halothane anesthetic technique: in all our patients anesthetized with this agent, CCT became prolonged proportionately as the halothane concentration changed. These data will be reported more fully elsewhere.

Within the limits of blood pressure manipulation during surgery, blood pressure changes unaccompanied by changes in halothane concentration were not associated with significant CCT change. During reversal of anesthesia as blood pressure was raised, there was no significant shortening of CCT in relation to such ele-

vation of the blood pressure. During reversal of respiration support in eight cases, we noted prolongation of conduction time, possibly related to transient elevations of arterial pCO₂, although insufficient measurements were made to confirm this factor. We found that conduction time could indicate excessive brain retraction and, although in the majority of our cases insertion of self-retaining retractors was unassociated with changes in conduction time, in four cases conduction time was prolonged when the retractors were inserted. An inter-hemispheric difference of more than 0.6 msec was seen in these cases, suggesting excessive retraction.

Interestingly, CCT showed some prolongation immediately after the application of a clip to an aneurysm neck in 12 of the 33 patients. The aneurysms involved were two terminal carotid artery aneurysms, two posterior communicating artery aneurysms, six middle cerebral artery aneurysms, and three basilar artery aneurysms. The effect on CCT of the application of temporary clips was demonstrated in one of four cases of clipping of the terminal carotid artery and in four of six proximal middle cerebral artery clips. None of the four anterior cerebral artery clips caused prolongation of CCT nor did the application of clips to any anterior communicating artery aneurysm. In this regard it is worth noting that, of eight cases with temporary bilateral anterior cerebral artery occlusion, seven suffered no postoperative deficits and one showed significant neurological disturbance. In this patient a very difficult anterior dissection required bilateral temporary occlusion of the A₁ segments for 3 minutes 15 seconds, followed by the development of akinetic mutism. It appears, therefore, that while assessment of SEP's in response to median nerve stimulation may be a reliable index of ischemia occurring in the middle cerebral artery territory, it may be inadequate to assess ischemia in the anterior cerebral artery distribution. We are investigating the possibility of using leg stimuli from the posterior tibial nerve, with midline recording in position Pz of the international 10/20 system, to cover situations of this type.

Throughout the investigation, careful notes of amplitudes of the SEP were made, but these were found of rather less value than measurements of CCT latencies. The SEP amplitude is easily disturbed by changing the position of the electrodes, by altering the intensity of the stimulus, and by the varying thickness of the scalp. Although these factors are more troublesome in attempted serial recording than when electrodes are in a constant position during surgery, amplitude is also more susceptible to electrical interference than is the latency of responses. Probably the most reliable amplitude measurement method is a comparison of the N₁₄ to N₂₀ amplitude ratio throughout surgery and, although this in general showed a decrease of the N₂₀ amplitude in relation to N₁₄ with increased delay of the response, there were circumstances when the N₂₀ amplitude transiently increased in a way that is difficult to explain at the present time, and the relationships par-

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ticularly during temporary occlusion appeared more reliable with CCT measurements.

The group of cases as a whole showed no postoperative neurological deficit. There was a discrepancy between a normal electrical recording and the postoperative deficit in one anterior communicating aneurysm case already mentioned, and in a further two cases there was a significant association between postoperative problems and perioperative CCT abnormalities.

The recording of SEP's is practicable during intracranial aneurysmal surgery. It in no way interferes with surgery and, although careful recording techniques are necessary because of the associated interference, the effects of halothane, retraction, and application of temporary clips for occlusion of a major vessel can be monitored by the technique. Our evidence so far suggests that prolongation of CCT up to 10 msec is not likely to be associated with postoperative deficit in terminal carotid or middle cerebral artery aneurysm cases, but a more detailed analysis of the safety period for complete loss of the evoked response without sequelae must clearly await further experience.

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